

# Revision of Dietary Reference Intakes for energy in preschool-age children<sup>1–4</sup>

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## ABSTRACT

**Background:** Dietary Reference Intakes (DRI) for energy aim to balance energy expenditure at a level of physical activity consistent with health and support adequate growth in children. DRIs were derived from total energy expenditure (TEE) measured by using the doubly labeled water (DLW) method; however, the database was limited in the 3–5-y-old range.

**Objective:** We reexamined the DRI for energy for preschool-age children.

**Design:** Ninety-seven healthy, normal-weight, preschool-age children (mean  $\pm$  SD age:  $4.5 \pm 0.9$  y) completed a 7-d DLW protocol while wearing accelerometer and heart rate-monitoring devices.

**Results:** Mean TEE and physical activity level (PAL) averaged  $1159 \pm 171$  kcal/d and  $1.34 \pm 0.14$ , respectively. TEE predicted by DRI equations agreed with observed TEE ( $+34$  kcal/d or 3%) if the sedentary PAL category was assumed but was overestimated by using the low active ( $+219$  kcal/d or 19%), active (398 kcal/d or 34%), and very active (593 kcal/d or 51%) PAL categories. PAL categories were redefined on the basis of the narrower PAL range observed in preschoolers (range: 1.05–1.70) compared with older children and adults (range: 1.0–2.5). Sex-specific nonlinear regression models were newly developed to predict TEE from age, weight, height, and new PAL categories. The mean absolute error of TEE prediction equations was  $0.00 \pm 35$  kcal/d or  $0.1 \pm 3\%$ . Ancillary measures, such as total accelerometer counts and total daily steps, that were significantly correlated ( $P = 0.01$ – $0.05$ ) with TEE ( $r = 0.26$ – $0.38$ ), TEE per kilogram ( $r = 0.31$ – $0.41$ ), and PAL ( $r = 0.36$ – $0.48$ ) may assist in the classification of preschoolers into PAL categories.

**Conclusions:** Current DRIs for energy overestimate energy requirements of preschool-age children because of the erroneous classification of children into PAL categories. New TEE prediction equations that are based on DLW and appropriate PAL categories are recommended for preschool-age children. This trial was registered at [clinicaltrials.gov](http://clinicaltrials.gov) as H12067. *Am J Clin Nutr* 2014;100:161–7.

## INTRODUCTION

Dietary Reference Intakes (DRIs)<sup>5</sup> for energy aim to balance total energy expenditure (TEE) at a level of physical activity consistent with health and support growth rates in children compatible with a healthy body size and composition. In contrast to previous Recommended Dietary Allowances derived from observed energy intakes in children (9), the 2002 Institute of Medicine (IOM) DRI committee decided to base energy requirements on TEE estimated by using the doubly labeled water (DLW)

method (15). The DLW method is considered more reliable than food intake data or the factorial approach for the estimation of TEE.

DLW is a noninvasive, stable-isotope method that captures the average TEE in free-living individuals over a period of time, typically 5–10 d in children, and reflects basal metabolism, the thermic effect of feeding, physical activity, thermoregulation, and the energy expended in the synthesis of newly deposited tissues (22).

The IOM DRI committee compiled a normative DLW database on infants and toddlers, children 3–18 y old, and adults who were healthy, free living, and normal weight (15). Sex-specific prediction equations for TEE were developed for each of these age groups by using its major contributors: age, sex, height, weight, and physical activity. Historically, energy requirements in adults were expressed as multiples of the basal metabolic rate (BMR) or physical activity level (PAL), whereby

$$\text{PAL} = \text{TEE} \div \text{BMR} \quad (1)$$

which provides a means of controlling for age, sex, and weight (7, 16). PAL associated with sustainable lifestyles in adults range from 1.2 to 2.5, where 1.2 represents the survival requirement, and 2.5 represents a very active lifestyle. In the development of DRI prediction equations for TEE, a 4-level ordinal variable was estimated from DLW PAL data and used in models to modify height and weight contributions to TEE. Nonlinear regression

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<sup>5</sup> Abbreviations used: BMR, basal metabolic rate; DLW, doubly labeled water; DRI, Dietary Reference Intake; FFM, fat-free mass; FM, fat mass; IOM, Institute of Medicine; PAL, physical activity level; RMSE, root mean squared error; TEE, total energy expenditure.

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models for boys and girls aged 3–18 y were generated for sedentary (PAL  $\geq 1.0$  but  $< 1.4$ ), low-active (PAL  $\geq 1.4$  but  $< 1.6$ ), active (PAL  $\geq 1.6$  but  $< 1.9$ ), and very active (PAL  $\geq 1.9$  but  $< 2.5$ ) categories.

Thus, current pediatric DRI for energy were based on DLW data of normal-weight children aged 3–18 y. Although a sizable database of DLW data was compiled that represent a wide range of ages, body sizes, and levels of physical activity, some age groups were underrepresented, and therefore, interpolations had to be performed. In particular, the normative DLW database was limited in the 3–5 y-old range with only two 3-y-olds and thirty-two 4-y-olds but sufficient 5-y-old children ( $n = 201$ ). Although it was recognized that the energy cost of physical activities such as walking and running, expressed as multiples of the BMR, increase from early childhood to adolescence (15), the impact of these age-related changes on daily PAL was not appreciated, and therefore, the same PAL categories were used in children and adults. In retrospect, mean PAL values in the normative DLW database increased from 1.39 to 1.56 to 1.80 in boys and from 1.48 to 1.60 to 1.69 in girls between the ages of 3–8, 9–13, and 14–18 y, respectively, largely because of the decrease in the BMR from 47 to 27 kcal  $\cdot$  kg $^{-1}$   $\cdot$  d $^{-1}$ . Mean PAL and BMR values in adults were 1.80 and 24 kcal  $\cdot$  kg $^{-1}$   $\cdot$  d $^{-1}$ , respectively.

In this analysis, we reexamined DRIs for energy in healthy, preschool-age children aged 3–5 y. Our specific aims were to 1) measure TEE by using the DLW method under free-living conditions in a sample of healthy, preschool-age children, 2) compare TEE measured by using DLW against that predicted by using DRI equation, 3) develop new TEE prediction equations for sedentary, low-active, active, and very active PAL categories, and 4) provide descriptors of PAL categories to classify and implement TEE prediction equations in preschool-age children.

## SUBJECTS AND METHODS

### Subjects

A cross-sectional design was used in which 97 healthy children completed the 7-d DLW method concomitant with accelerometry and heart-rate monitoring. The Institutional Review Board for Human Subject Research for Baylor College of Medicine and Affiliated Hospitals approved the protocol. Enrollment began in May 2010. All parents or primary caretakers gave written informed consent to participate in the study.

Healthy preschool-age children, aged 3–5 y, were eligible for the study. Exclusion criteria included any medical illness or medication that affected growth or limited participation in physical activities or sports. Children who were taking prescription drugs or had chronic diseases including metabolic or endocrine disorders, asthma treated with steroids, or sleep apnea were excluded from the study. For inclusion in the analysis, children were required to have a BMI (in kg/m $^2$ ) calculated as weight divided by the square of height, between 5th and 85th percentiles according to the CDC (17).

### Methods

#### Anthropometric measures and body composition

Body weight to the nearest 0.1 kg was measured with a digital balance, and height to the nearest 1 mm was measured with

a stadiometer in duplicate and repeated if the 2 measurements differed by  $> 0.2$  kg or 0.5 cm, respectively. Body composition was measured by using dual-energy X-ray absorptiometry (Delphi-A, software version 12; Hologic). Fat-free mass (FFM) and fat mass (FM) were also estimated by  $^2\text{H}$  and  $^{18}\text{O}$  dilution as part of the DLW method. Total body water was computed from  $^{18}\text{O}$  and  $^2\text{H}$  isotope dilution spaces by applying a 1% correction for  $^{18}\text{O}$  and a 4% correction for  $^2\text{H}$  to account for the exchange with nonaqueous organic compounds and converted to FFM by using age- and sex-specific hydration constants published by Lohman et al (18).

#### Accelerometry and heart-rate monitoring

A small (7-mm-thick, 33-mm-diameter, 10 g total weight) device (Actiheart; CamNtech Ltd), equipped with a uniaxial accelerometer and electrocardiogram signal processor was affixed to the chest by using 2 electrodes (Skintact Premier; Leonhard Lang GmbH). A triaxial accelerometer (ActiGraph GT3X+; ActiGraph) was worn above the iliac crest of the right hip with an adjustable elastic belt and used to measure the amount and frequency of movement of children. Details of the devices, their programming and processing have been published elsewhere (5). Briefly, physical activity, steps, and heart rate were recorded for an average of  $6.6 \pm 0.8$  d. Nonwear time was defined as  $\geq 20$  min of consecutive zero counts if the interval was not identified as nighttime sleep, nap time, or device removal for bathing or aquatic activities in records completed by parents. A valid day required  $\geq 1000$  min wear time/d.

#### DLW method

TEE was measured over a 7-d period by using the DLW method (1). After collection of baseline urine samples, each participant received, by mouth, 0.086 g  $^2\text{H}_2\text{O}$ /kg body weight at 99.9 atom%  $^2\text{H}$  and 1.38 g  $\text{H}_2^{18}\text{O}$ /kg body weight at 10 atom%  $^{18}\text{O}$  (Isotec). Seven postdose urine samples (1 mL) were collected at home on days 1–7. Urine samples were stored frozen before analysis by using gas isotope ratio mass spectrometry (28). For stable-hydrogen isotope ratio measurements, 10  $\mu\text{L}$  urine without additional treatment were reduced to hydrogen gas with 200 mg Zn reagent at 500°C for 30 min (27).  $^2\text{H}:^1\text{H}$  isotope ratios of the hydrogen gas were measured with a Finnigan Delta-E gas isotope ratio mass spectrometer (Finnigan MAT). For stable-oxygen isotope ratio measurements, 100  $\mu\text{L}$  urine was allowed to equilibrate with 300 mbar  $\text{CO}_2$  of known  $^{18}\text{O}$  content at 25°C for 10 h by using a VG ISOPREP-18 water- $\text{CO}_2$  equilibration system (VG Isogas Ltd). At the end of the equilibration,  $^{18}\text{O}:^{16}\text{O}$  isotope ratios of  $\text{CO}_2$  were measured with an VG SIRA-12 gas-isotope ratio mass spectrometer (VG Isogas Ltd).

Isotopic results were normalized against the following 2 international water standards: Vienna-Standard Mean Ocean Water and Standard Light Antarctic Precipitation (12). The isotope dilution spaces for  $^2\text{H}$  ( $N_{\text{H}}$ ) and  $^{18}\text{O}$  ( $N_{\text{O}}$ ) were calculated as follows:

$$N_{\text{H}} \text{ or } N_{\text{O}}(\text{mol}) = (d \times A \times E_{\alpha}) \div (\alpha \times E_{\text{d}} \times 18.02) \quad (2)$$

where  $d$  is the dose of  $^2\text{H}_2\text{O}$  or  $\text{H}_2^{18}\text{O}$  in grams,  $A$  is the amount of laboratory water in grams used in the dose dilution,  $\alpha$  is the amount of  $^2\text{H}_2\text{O}$  or  $\text{H}_2^{18}\text{O}$  in grams added to the laboratory water in the dose dilution,  $E_{\alpha}$  is the rise in  $^2\text{H}$  or  $^{18}\text{O}$  abundance

in the laboratory water after the addition of the isotopic water, and  $E_d$  is the rise in  $^2\text{H}$  or  $^{18}\text{O}$  abundance in urine samples at time zero obtained from zero-time intercepts of  $^2\text{H}$  and  $^{18}\text{O}$  decay curves in urine samples. Carbon dioxide production ( $\dot{V}\text{CO}_2$ ) was calculated from fractional turnover rates of  $^2\text{H}$  ( $k_{\text{H}}$ ) and  $^{18}\text{O}$  ( $k_{\text{O}}$ ) as follows:

$$\dot{V}\text{CO}_2(\text{mol/d}) = 0.45537 \times (k_{\text{O}} \times N_{\text{O}} - k_{\text{H}} \times N_{\text{H}}) \quad (3)$$

$\dot{V}\text{CO}_2$  was converted to TEE by using Weir's equation (26) as follows:

$$\text{TEE}(\text{kcal/d}) = 22.4 \times (1.106 \times \dot{V}\text{CO}_2 + 3.941 \times \dot{V}\text{O}_2) \quad (4)$$

where  $\dot{V}\text{O}_2$  was calculated by using the relation

$$\dot{V}\text{O}_2 = \dot{V}\text{CO}_2 \div \text{FQ} \quad (5)$$

with the assumption of a food quotient (FQ) (2) equal to 0.86. PAL was calculated as the ratio of TEE over the BMR computed according to Schofield (23).

#### Statistics

Data are summarized as means  $\pm$  SDs. Descriptive statistics were performed with STATA software (release 13; StataCorp LPs). Nonlinear regression was used to develop new prediction equations for TEE. Goodness-of-fit methods were used to assess competing models on the basis of their agreement between measured and predicted values. Mean absolute errors, mean percentage errors, and root mean squared errors (RMSEs) were computed to assess the accuracy of final prediction equations against DLW. Agreement between observed and predicted TEEs was assessed by using the graphical method of Bland and Altman (3).

#### RESULTS

Ninety-seven healthy, normal-weight children aged 3–5 y (mean  $\pm$  SD age:  $4.5 \pm 0.9$  y) participated in the study. The sample was balanced for age and sex and diverse in terms of race-ethnicity (32 white, 29 black, 29 Hispanic, 2 Asian, and 5 multiracial subjects). Anthropometric measures and body composition of children are summarized in **Table 1**. Weight-for-age, height-for-age, and BMI  $z$  scores were within normal limits. Mean percentages of FM were 26%, 26% and 27% by using DXA and  $^2\text{H}$ , and  $^{18}\text{O}$  dilutions, respectively.

Mean 7-d TEEs and other variables generated by using the DLW method are summarized for the preschool-age children in **Table 2**. TEEs increased significantly with age ( $1050 \pm 118$ ,  $1196 \pm 173$ , and  $1234 \pm 163$  kcal/d in 3-, 4-, and 5-y-olds, respectively;  $P = 0.001$ ) and differed slightly by sex ( $P = 0.03$ ). No significant differences in TEE were detected by race-ethnicity. The sex difference persisted even after adjustment for weight and height or FFM, FM, and height. With the use of linear regression, child characteristics (age, weight, and height) explained 46% and 54% of the variance in TEE in boys and girls, respectively. Note the wide variation of TEE (784–1674

**TABLE 1**

Anthropometric measures and body composition of preschool-age children aged 3–5 y<sup>1</sup>

	Boys (n = 48)	Girls (n = 49)	Total (n = 97)
Age (y)	$4.5 \pm 0.9^2$	$4.6 \pm 0.9$	$4.5 \pm 0.9$
Weight (kg)	$17.4 \pm 2.7$	$17.1 \pm 2.5$	$17.2 \pm 2.6$
Height (m)	$1.06 \pm 0.08$	$1.06 \pm 0.07$	$1.06 \pm 0.08$
BMI ( $\text{kg/m}^2$ )	$15.3 \pm 0.7$	$15.2 \pm 0.8$	$15.3 \pm 0.8$
Weight-for-age percentile	$48 \pm 26$	$48 \pm 24$	$48 \pm 25$
Height-for-age percentile	$54 \pm 29$	$56 \pm 27$	$55 \pm 28$
BMI-for-age percentile	$42 \pm 22$	$45 \pm 23$	$44 \pm 22$
Weight-for-age $z$ score	$-0.06 \pm 0.78$	$-0.08 \pm 0.75$	$-0.07 \pm 0.76$
Height-for-age $z$ score	$0.18 \pm 1.06$	$0.21 \pm 0.94$	$0.19 \pm 1.00$
BMI-for-age $z$ score	$-0.26 \pm 0.66$	$-0.16 \pm 0.68$	$-0.21 \pm 0.67$
DXA FFM ( $\text{kg}$ ) <sup>3</sup>	$13.3 \pm 2.5$	$12.2 \pm 2.1$	$12.7 \pm 2.3$
DXA FM ( $\text{kg}$ ) <sup>4</sup>	$4.1 \pm 0.9$	$4.8 \pm 1.0$	$4.5 \pm 1.0$
DXA FM (% of weight) <sup>4</sup>	$23.7 \pm 4.6$	$28.6 \pm 4.8$	$26.2 \pm 5.3$
$^2\text{H}$ FFM ( $\text{kg}$ ) <sup>3</sup>	$13.2 \pm 2.1$	$12.2 \pm 1.9$	$12.7 \pm 2.1$
$^2\text{H}$ FM ( $\text{kg}$ ) <sup>3</sup>	$4.2 \pm 0.8$	$4.9 \pm 1.1$	$4.5 \pm 1.0$
$^2\text{H}$ FM (%) <sup>4</sup>	$24.2 \pm 3.1$	$28.6 \pm 4.1$	$26.4 \pm 4.2$
$^{18}\text{O}$ FFM ( $\text{kg}$ ) <sup>4</sup>	$13.0 \pm 2.1$	$12.0 \pm 1.9$	$12.5 \pm 2$
$^{18}\text{O}$ FM ( $\text{kg}$ ) <sup>4</sup>	$4.4 \pm 0.8$	$5.0 \pm 1.1$	$4.7 \pm 1.0$
$^{18}\text{O}$ FM (%) <sup>4</sup>	$25.1 \pm 3.1$	$29.5 \pm 4.1$	$27.3 \pm 4.2$

<sup>1</sup> DXA, dual-energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass.

<sup>2</sup> Mean  $\pm$  SD (all such values).

<sup>3,4</sup> Sex effect: <sup>3</sup> $P < 0.02$ , <sup>4</sup> $P < 0.001$ .

kcal/d) even after adjustment for body weight ( $47\text{--}91 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$ ).

TEE data are displayed in **Figure 1** as a function of age and weight along with data from the DRI normative DLW database from birth to 8 y of age. Newly acquired TEE data complemented the underrepresented 3–5-y age range of the DRI normative DLW database. To evaluate the DRI for energy in preschoolers, TEE was predicted from age, weight, and height by using sex-specific DRI equations for each of the 4 PAL categories. If the sedentary PAL category was assumed, the predicted TEE was in close agreement with that measured by DLW (34 kcal/d or a 3% overestimation). If the low-active PAL category was assumed, the difference between predicted and measured TEEs was 219 kcal/d or a 19% overestimation. If the active PAL category was assumed, the difference between predicted and measured was 398 kcal/d or a 34% overestimation, and if the very active PAL category was assumed, the difference between predicted and measured amounted to 593 kcal/d or a 51% overestimation. The predicted TEE values with the use of DRI equations compared with measured TEE values are displayed graphically in **Figure 2**.

The observed distribution of PAL values for preschool-age children (PAL: 1.05–1.70) was narrower than the range in the DRI normative DLW database (PAL: 1.0–2.5) and led to the overestimation of TEE by using DRI equations. To compute the PAL, the BMR was estimated by using Schofield's prediction equations for boys and girls (23) because measured values were not available for all subjects. In the DRI document, basal energy expenditure equations were provided; however, basal energy expenditure values were significantly higher than those predicted by Schofield's equations ( $934 \pm 73$  compared with  $862 \pm 66$  kcal/d) and higher than measured rates in a subset of 48 preschoolers ( $916 \pm 55$  compared with  $823 \pm 89$  kcal/d) ( $P = 0.001$ ).



**TABLE 2**  
TEE measured by using the doubly labeled water method in preschool-age children aged 3–5 y<sup>1</sup>

	Boys (n = 48)	Girls (n = 49)	Total (n = 97)
<sup>2</sup> H dilution space (N <sub>H</sub> ) (kg) <sup>2</sup>	10.6 ± 1.7 <sup>3</sup>	9.9 ± 1.5	10.3 ± 1.6
<sup>18</sup> O dilution space (N <sub>O</sub> ) (kg) <sup>2</sup>	10.2 ± 1.6	9.5 ± 1.5	9.8 ± 1.6
<sup>2</sup> H: <sup>18</sup> O dilution spaces (N <sub>H</sub> :N <sub>O</sub> )	1.04 ± 0.01	1.04 ± 0.01	1.04 ± 0.01
<sup>2</sup> H turnover rate (k <sub>H</sub> ) (d)	−0.13 ± 0.03	−0.12 ± 0.03	−0.13 ± 0.03
<sup>18</sup> O turnover rate (k <sub>O</sub> ) (d)	−0.17 ± 0.03	−0.17 ± 0.03	−0.17 ± 0.03
<sup>2</sup> H ln DOB compared with days (r)	−0.996 ± 0.006	−0.997 ± 0.004	−0.997 ± 0.005
<sup>18</sup> O ln DOB compared with days (r)	−0.997 ± 0.005	−0.998 ± 0.003	−0.997 ± 0.004
$\dot{V}\text{CO}_2$ (mol/d)	9.43 ± 1.51	8.83 ± 1.1	9.13 ± 1.35
BMR (kcal/d) <sup>4</sup>	893 ± 63	831 ± 54	862 ± 66
TEE (kcal/d) <sup>2</sup>	1197 ± 192	1122 ± 140	1159 ± 171
TEE (kcal · kg <sup>−1</sup> · d <sup>−1</sup> ) <sup>5</sup>	69.4 ± 8.1	66.3 ± 6.8	67.8 ± 7.6
PAL	1.34 ± 0.16	1.35 ± 0.12	1.34 ± 0.14

<sup>1</sup> BMR, basal metabolic rate; DOB,  $\delta$  over baseline enrichment; PAL, physical activity level; TEE, total energy expenditure;  $\dot{V}\text{CO}_2$ , carbon dioxide production.

<sup>2,4,5</sup> Sex effect: <sup>2</sup>P = 0.03, <sup>4</sup>P < 0.001, <sup>5</sup>P = 0.045.

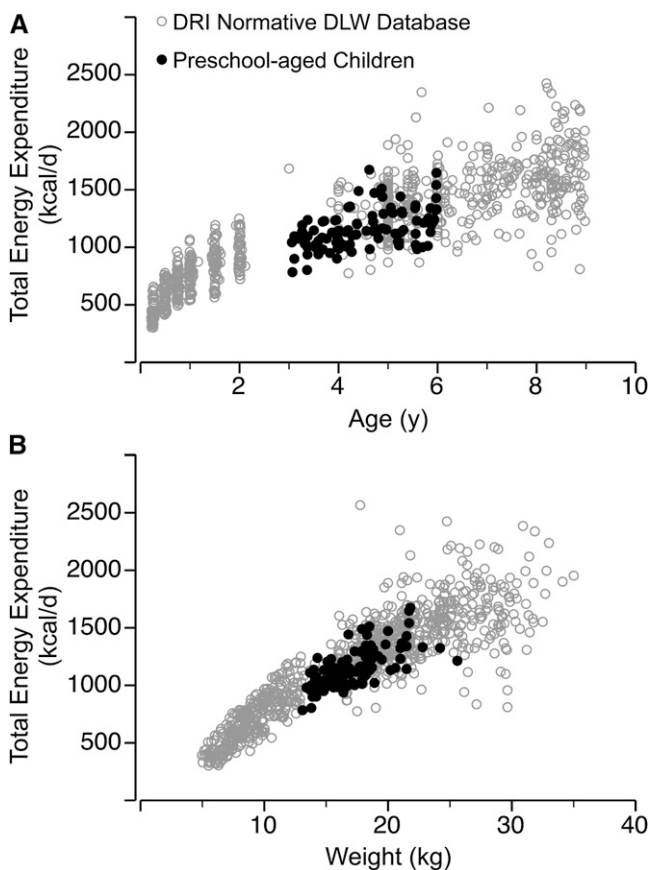
<sup>3</sup> Mean ± SD (all such values).

On the basis of the mean ± 1 SD of the observed PAL of the preschool-age children, PAL thresholds were redefined for sedentary (PAL ≥ 1.0 but < 1.2), low-active (PAL ≥ 1.2 but < 1.35), active (PAL ≥ 1.35 but < 1.5), and very active (PAL ≥ 1.5) categories. Nonlinear regression models were developed

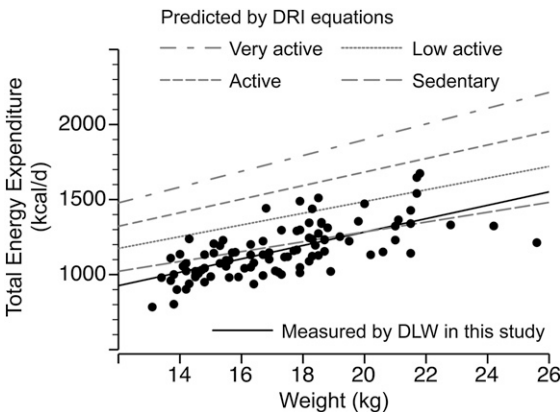
to predict TEE from age, weight, height, and the new PAL categories separately for boys and girls. There are physiologic reasons for considering the following additive mode:

$$\text{TEE} = b_0 + b_1 \times \text{age} + \text{PA}(b_2 \times \text{weight} + b_3 \times \text{height}) \quad (6)$$

where TEE is in kilocalories per day, age is in years, weight is in kilograms, and height is in meters. The variables of this model have a direct interpretation in terms of energy expenditure. To fit this model, we used nonlinear least squares, which uses an iterative procedure to estimate unknown variables. To start the iterative procedure, we needed to set starting values of variables. Toward this end, we set PA = 1 for the sedentary PAL category, PA = 1 + a<sub>2</sub> for the low-active PAL category, 1 + a<sub>3</sub> for the active PAL category, and 1 + a<sub>4</sub> for the very active PAL category. For the iteration, the initial values of a<sub>2</sub>, a<sub>3</sub>, and a<sub>4</sub> were set equal to zero, and convergence was achieved after just a few iterations. An investigation of the model assumptions and residual analysis indicated that the model fit the data well and was appropriate for describing the data. The PA coefficients (a<sub>1</sub>, a<sub>2</sub>,



**FIGURE 1.** TEE of preschool-age children measured in this study (n = 97) (solid circles), with data from the DRI normative DLW database from birth to 8 y of age (n = 821) (open circles), are plotted as a function of (A) age and (B) weight. DLW, doubly labeled water; DRI, Dietary Reference Intake; TEE, total energy expenditure.



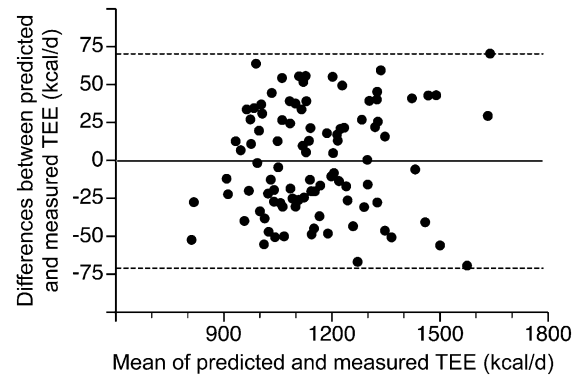
**FIGURE 2.** TEE of preschool-age children (n = 97) predicted by using DRI equations for sedentary, low-active, active, and very active physical activity categories compared with TEE measured in the current study by using the DLW method (solid circles). DLW, doubly labeled water; DRI, Dietary Reference Intake; TEE, total energy expenditure.



$a_3$ , and  $a_4$ ) were solved simultaneously for the 4 PAL categories while keeping the equations parallel, as was done in the DRI nonlinear regression equations.

In nonlinear regression models, age was shown to be non-significant ( $P = 0.72$  in boys;  $P = 0.92$  in girls), and therefore, age was dropped from the models. Parenthetically, regression coefficients and the RMSE were nearly identical with or without age in the model. Sex-specific prediction equations that were based on weight, height, and PAL accounted for 96.3% and 94.0% of the variance in TEE in boys and girls, respectively. An examination of residual plots by comparing measured and predicted TEEs revealed no bias with respect to age, weight, or height. Mean absolute errors, mean percentage errors, and RMSEs, shown in **Table 3**, were computed to assess the accuracy of TEE prediction equations against DLW. The concordance between observed and predicted TEEs ( $0.00 \pm 34.2$  kcal/d) is graphically displayed by using a Bland and Altman plot in **Figure 3**; there was no bias between differences and the means of observed and predicted TEE values ( $r = -0.10$ ,  $P = 0.31$ ). An estimate of the error in predicting TEE for individuals can be derived from the absolute mean error or mean percentage error provided in Table 3. From the observed variance, the predicted TEE would be expected to be within  $\pm 68$  kcal/d or  $\pm 6.4\%$  for 95% of individuals within the population. The Bland and Altman plot of differences between predicted and measured TEEs compared with means of the same values displays 95% CIs for individuals.

The observed TEE and its derivatives are described for the 4 new PAL categories in **Table 4**. As expected, TEE in absolute



**FIGURE 3.** Bland and Altman plot of differences between predicted and measured TEEs in preschool-age children ( $n = 97$ ) compared with means of the same values. The horizontal solid line represents the mean difference and the dashed lines represent the  $\pm 2$ -SD intervals. TEE, total energy expenditure.

terms or adjusted by weight increased across the 4 PAL categories. PAL increased from 1.13 in the sedentary category to 1.57 in the very active category.

New equations for predicting TEEs in preschool-age children are summarized below. For normal-weight boys, aged 3–5 y, the prediction equation for TEE is as follows:

$$\text{TEE(kcal/d)} = 358 + \text{PA} \times [16.0 \times \text{weight(kg)} + 356 \times \text{height(m)}] \quad (7)$$

where PA = 1.0 if PAL is estimated to be  $\geq 1.0$  but  $< 1.2$  (sedentary), PA = 1.20 if PAL is estimated to be  $\geq 1.2$  but  $< 1.35$  (low active), PA = 1.37 if PAL is estimated to be  $\geq 1.35$  but  $< 1.5$  (active), and PA = 1.64 if PAL is estimated to be  $\geq 1.5$  (very active).

For normal-weight girls, aged 3–5 y, the prediction equation for TEE is as follows:

$$\text{TEE(kcal/d)} = 352 + \text{PA} \times [11.6 \times \text{weight(kg)} + 347 \times \text{height(m)}] \quad (8)$$

where PA = 1.0 if PAL is estimated to be  $\geq 1.0$  but  $< 1.2$  (sedentary), PA = 1.25 if PAL is estimated to be  $\geq 1.2$  but  $< 1.35$  (low active), PA = 1.46 if PAL is estimated to be  $\geq 1.35$  but  $< 1.5$  (active), and PA = 1.62 if PAL is estimated to be  $\geq 1.5$  (very active).

The application of the TEE prediction equations requires the classification of children into one of the 4 PAL categories. To provide some objective measure of physical activity in preschool-age children, mean values by PAL category are presented in Table 4 for accelerometer counts and total daily steps. The mean wear time was  $1412 \pm 26$  min/d for the 7-d monitoring. Actiheart and Actigraph total accelerometer counts and total daily steps were significantly correlated ( $P = 0.01$ – $0.05$ ) with TEE ( $r = 0.26$ – $0.38$ ), TEE per kilogram ( $r = 0.31$ – $0.41$ ), and PAL ( $r = 0.36$ – $0.48$ ).

## DISCUSSION

Newly acquired TEE data closed the 3–5-y age gap in the DRI normative DLW database and suggested a need to revise DRI

**TABLE 3**

Nonlinear regression models for the prediction of TEE in boys and girls aged 3–5 y<sup>1</sup>

	Values	<i>t</i>	<i>P</i>
<b>Boys aged 3–5 y</b>			
Constant ( $b_0$ )	$358 \pm 129$	2.77	0.008
$a_2$	$0.198 \pm 0.051$	3.90	0.001
$a_3$	$0.370 \pm 0.082$	4.51	0.001
$a_4$	$0.636 \pm 0.130$	4.90	0.001
Weight coefficient ( $b_2$ )	$16.0 \pm 4.76$	3.36	0.002
Height coefficient ( $b_3$ )	$355.6 \pm 187.8$	1.89	0.065
$R^2$	0.963	—	—
Absolute error (kcal/d) <sup>2</sup>	$0.0 \pm 36.8$	—	—
Percentage error <sup>2</sup>	$0.1 \pm 3.0$	—	—
RMSE (kcal/d)	36.5	—	—
<b>Girls aged 3–5 y</b>			
Constant ( $b_0$ )	$352 \pm 114$	3.09	0.004
$a_2$	$0.248 \pm 0.080$	3.12	0.003
$a_3$	$0.456 \pm 0.120$	3.81	0.001
$a_4$	$0.619 \pm 0.156$	3.97	0.001
Weight coefficient ( $b_2$ )	$11.6 \pm 3.45$	3.37	0.002
Height coefficient ( $b_3$ )	$346.8 \pm 152.3$	2.28	0.028
$R^2$	0.940	—	—
Absolute error (kcal/d) <sup>2</sup>	$0.0 \pm 34.2$	—	—
Percentage error <sup>2</sup>	$0.1 \pm 3.2$	—	—
RMSE (kcal/d)	33.9	—	—

<sup>1</sup> All values are coefficients  $\pm$  SEs unless otherwise designated. Nonlinear regression models in which TEE is in kilocalories per day, weight is in kilograms, and height is in meters. Physical activity coefficients are designated  $a_2$ ,  $a_3$ , and  $a_4$  for low-active, active, and very active categories. RMSE, root mean squared error; TEE, total energy expenditure.

<sup>2</sup> All values are means  $\pm$  SEs.

**TABLE 4**Descriptors of PAL categories in preschool-age children<sup>1</sup>

	Sedentary PAL	Low active PAL	Active PAL	Very active PAL
Total energy expenditure and derivatives				
<i>n</i>	13	42	25	17
Total energy expenditure (kcal/d)	968 ± 116 <sup>2</sup>	1086 ± 84	1223 ± 90	1405 ± 143
Total energy expenditure (kcal · kg <sup>-1</sup> · d <sup>-1</sup> )	59.6 ± 5.4	65.4 ± 5.8	69.6 ± 5.9	76.2 ± 5.9
Physical activity level	1.13 ± 0.05	1.28 ± 0.04	1.41 ± 0.04	1.57 ± 0.06
Ancillary measurements of physical activity level				
Total activity				
Actiheart device (counts/d) <sup>3</sup>	92,699 ± 27,134	95,187 ± 26,011	103,981 ± 22,915	120,212 ± 27,921
Actigraph device <i>x</i> -axis (counts/d) <sup>4</sup>	448,155 ± 91,714	449,202 ± 102,665	513,522 ± 96,727	617,135 ± 152,568
Actigraph device vector magnitude (counts/d)	1,027,449 ± 142,937	1,097,268 ± 197,052	1,216,795 ± 180,256	1,362,043 ± 241,604
Step count: Actigraph device (steps/d)	7850 ± 1000	8638 ± 1723	9501 ± 2065	10,634 ± 1848

<sup>1</sup> PAL, physical activity level.<sup>2</sup> Mean ± SD (all such values).<sup>3</sup> Actiheart (CamNtech Ltd.).<sup>4</sup> ActiGraph GT3X+ (ActiGraph).

prediction equations for TEEs of preschool-age children (15). Newly acquired TEE values for 3–5-y-olds were consistent with existing DLW data for 0–2-y-olds and 5–8-y-olds. However, prediction of TEEs by using low-active, active and very active PAL categories of DRI equations resulted in serious overestimations of TEEs. The erroneous predictions stemmed from the fact that PAL categories used are not developmentally appropriate for this young age group. Observed PAL values gradually increase from infancy to early childhood, primarily because of the decreasing BMR (the denominator of the PAL ratio) but also because of the developmental maturation of the growing child, which results in greater muscle mass, motor coordination, and physical capability (10).

On the basis of the PAL distribution of preschoolers, we redefined PAL thresholds for sedentary, low-active, active, and very active categories to reflect their narrower range compared with older children and adults. The distribution of PAL values observed in our study (mean 1.34; range: 1.1–1.7) was consistent with the DRI normative DLW database (15) in which the mean PAL observed in 3–5-y-olds was  $1.38 \pm 0.14$  (range: 1.2–1.8). On the basis of DLW, heart-rate monitoring, and time-motion activity diaries, mean PAL values were 1.4–1.5 in children <5-y old (25). Other publications confirmed the lower mean PAL in preschool-age children, ranging from 1.24 to 1.6 (8, 13, 14, 19, 21, 24). On the basis of our observations of healthy preschool-age children, we suggest the following PAL categories:  $\geq 1.0$  but <1.2 (sedentary),  $\geq 1.2$  but <1.35 (low active),  $\geq 1.35$  but <1.5 (active), and  $\geq 1.5$  (very active).

In this young age group, health can be defined as normal growth and development, the absence of disease, and the ability to participate in social and physical activities. Throughout childhood, a range of body sizes and growth rates compatible with health are acknowledged, recognizing the genetic variability in children. Optimal body composition and energy expenditure on the basis of short- or long-term outcomes have not been defined for this age group. As in the IOM DRI report, our data represent healthy (defined as the absence of disease) children with BMI between 5th and 85th percentiles. Our exclusion criteria entailed overweight and obesity and any medical illness or medication that affected growth or limited participation in physical activities or sports. Children who were taking pre-

scription drugs or with chronic diseases including metabolic or endocrine disorders, asthma treated with steroids, and sleep apnea were excluded. Therefore, our data represent the range of energy expenditure and physical activity observed in healthy preschoolers growing normally. In our presentation, we have provided guidance for the prediction of TEE on the basis of weight, height, and physical activity for boys and girls, with recognition of the variation in children without being prescriptive.

The physical activity of our preschoolers on the basis of step counts appeared similar to that of other groups. The mean daily step count in our preschoolers was 9145 steps/d. In Belgium, 4–5-y-old preschoolers accumulated 9980 steps/d (6). In Canada, daily step counts were 7529 steps/d in 30 preschoolers (20). In a larger study of Canadian preschoolers ( $n = 133$ ), 3–4-y-old children had 8513 steps/d, and 5-y-old children had 9886 steps/d (11).

We present new prediction equations for TEE for preschool-age children. In this age group, weight and physical activity are the major predictors of TEE. Even in these young children, there is considerable variability in the energy expended in physical activity that justifies the incorporation of a PAL factor in the prediction of TEE. We showed that age, weight, and height explained 46% and 54% of the variance in TEE in boys and girls, respectively. The addition of the PAL factor increased the variance in TEE explained to 94–96% in boys and girls. Consequently, we formulated sex-specific TEE prediction equations on the basis of weight, height, and PAL (we omitted age because of collinearity). DRI prediction equations for normal-weight boys and girls aged 3–18 y were developed from age, height, weight, and PAL category; the RMSEs were 82.8 kcal/d for boys and 96.7 kcal/d for girls aged 3–18 y. RMSEs for our new TEE prediction equations were smaller than those for the DRI prediction equation probably because of our narrower age range;  $r^2$  values were similar.

We recommend the new sex-specific prediction equations for TEEs in preschool-age children. To compute the estimated energy requirement as done in the DRI, the energy deposition for growth, which was estimated to be an average of 20 kcal/d in this age group of 3–8-y-olds should be added to predicted TEEs (15). To use the prediction equations for TEE, children must be



classified into a PAL category. In the DRI report, age-specific guidance was given to interpret PAL categories in terms of walking equivalents (15). In the current article, we have provided ancillary descriptors that could be used to classify groups of children or individual children into PAL categories. As with any classification system, there will be overlaps at boundaries between PAL categories, but an objective ancillary measure would improve on subjective judgment. Pedometers and accelerometers are becoming more ubiquitous not only in research but also in the public (4). Pedometry is a simple, inexpensive method that objectively records the number of steps in a given epoch and has been shown to correlate highly with moderate-vigorous physical activity in preschoolers (6, 20). Accelerometry is more expensive and labor intensive but objectively measures the frequency, intensity, and duration of movement as well as step counts. In this research project, children wore Actiheart and Actigraph devices for 7 d to coincide with the DLW washout period. Total accelerometer counts and total daily steps were moderately correlated with TEEs and PALs and, thus, provided some measure to classify children into PAL categories.

In conclusion, current DRIs for energy overestimate energy requirements of preschool-age children because of the erroneous PAL classification of children. New TEE prediction equations that are based on DLW and developmentally appropriate PAL categories are recommended for preschool-age children.

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